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Symposium proceedings from the First Japan-America Frontiers of Engineering Symposium, held Nov. 2-4, 2000. Topics covered: earthquake engineering, design and integration of functional inorganic materials, manufacturing, and biotechnology. Book includes 15 abstracts of papers presented, text of dinner speech, and background about the symposium.

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Japan-America FRONTIERS OF ENGINEERING Symposium 2000

Symposium Proceedings

Nara, Japan
November 2–4, 2000

Japan Science and Technology Corporation
U.S. National Academy of Engineering
Engineering Academy of Japan

Japan-America Frontiers of Engineering
Symposium Series
2000

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Preface

On November 2–4, 2000, 60 outstanding Japanese and American engineers from industry, academia, government labs, and other research institutions gathered for the First Japan-America Frontiers of Engineering Symposium (JAFOE) in Nara, Japan. Convened by the U.S. National Academy of Engineering (NAE), the Engineering Academy of Japan (EAJ), and the Japan Science and Technology Corporation (JST), this exciting and unique meeting included presentations and discussion of leading-edge research and technical work in four areas: earthquake engineering, ceramics, manufacturing, and biotechnology. The primary purpose of this book is to convey something about the content of the meeting through abstracts of the presentations and other meeting materials reprinted herein, as well as to inform the reader about the underpinning philosophy of the Frontiers of Engineering program.

ORIGINS AND GOALS OF THE ACTIVITY

Since 1995, the U.S. National Academy of Engineering has held an annual Frontiers of Engineering Symposium that brings together 100 outstanding engineers (ages 30–45) from U.S. companies, universities, and government labs to discuss pioneering research and technical work across a range of engineering fields. The goal of the symposium series is to introduce these engineers to each other, challenge them to think about developments and problems at the frontiers of areas different from their own, and thereby facilitate collaborative work, the transfer of new techniques and approaches across fields, and establishment of contacts among the next generation of engineering leaders.

In 1998, NAE held its first bilateral Frontiers meeting—with Germany—and has held three German-American Frontiers of Engineering symposia to date. Due to the success of that bilateral Frontiers symposium, NAE approached the Engineering Academy of Japan with the idea of initiating a Japan-America Frontiers of Engineering Symposium. EAJ was very receptive to the idea and sent three Japanese engineers as observers to the 1998 U.S. Frontiers of Engineering meeting held in Irvine, California. It was agreed at that time that the first Japan-America Frontiers of Engineering meeting would be held in Japan in 2000, and planning commenced. Organizational work was carried out on the U.S. side by the National Academy of Engineering. On the Japanese side, EAJ worked with and was supported by the Japan Science and Technology Corporation, a government agency under the auspices of the Ministry of Education, Culture, Sports, Science and Technology.

The JAFOE activity aims to bring together outstanding, early-career Japanese and American engineers from industry, universities, and other research institutions to introduce their areas of engineering research and technical work, thereby facilitating an interdisciplinary transfer of knowledge and methodology that could eventually lead to the development of cooperative networks of young engineers from both countries. It is anticipated that conferences will be held annually, alternately in Japan and the United States, with about 30 engineers from each country participating. An organizing committee comprised of Japanese and U.S. engineers develops the program for the event and assists in the selection of participants.

CONTENT OF THE FIRST JAFOE SYMPOSIUM

Yasutaka Iguchi, professor and vice director or the New Industry Creation Hatchery Center at Tohoku University, and Robert H. Wagoner, professor, Department of Materials Science and Engineering at Ohio State University, co-chaired the organizing committee and the symposium. Typically, two Japanese and two Americans gave presentations in each of the four broad engineering areas mentioned above: earthquake engineering, ceramics, manufacturing, and biotechnology. Presentations covered such specific topics as applications of new technologies in geotechnical earthquake engineering, atomic structure control of electronic ceramic thin films, sub-50 nanometer lithography, and drug delivery technologies. Speakers had been asked to tailor their talks to a technically sophisticated but non-specialist audience and to address such questions as: What are the frontiers in their field? What experiments, prototypes, and design studies are completed and in progress? What new tools and methodologies are being used? What are the current limitations on advances? What is the theoretical, commercial, societal, and long-term significance of the work?

In addition to excellent presentations in the four topic areas, another highlight of the symposium was the dinner speech by Mr. Shoichiro Yoshida, president of Nikon Corporation. Mr. Yoshida shared his views, formed by his 44-year experience at Nikon, on the historical characteristics of technology development in Japan

and challenges Japanese companies face as they move into the 21st century. These challenges include creating original technologies, seeding synergistic technologies, and developing relationships with new and growing industries. The text of his talk is included in this volume.

The meeting was designed to give ample opportunity for discussion and networking among the participants through Q&A time after each presentation in the plenary sessions as well as poster sessions that allowed each participant to showcase and talk about his/her technical work or research. In addition, various cultural and technical events were arranged, including tours of historical sites in Nara, the ancient Japanese capital; a Noh performance; and visits to ATR Institute, an information technology research facility, Sekisui, and Sharp Corporation. With a view to possibly expanding this meeting to include engineers from other Pacific Rim countries at some time in the future, several early-career engineers from China and South Korea were invited to attend as well. A second Japan-America Frontiers of Engineering Symposium will be held November 29–December 1, 2001, in Irvine, California.

IN APPRECIATION

We would like to express our appreciation to our sponsors—the Japan Science and Technology Corporation, the U.S. Office of Naval Research, and the U.S. National Science Foundation—for their support of this symposium. We also would like to thank the members of the Symposium Organizing Committee for their work in planning this event.

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EARTHQUAKE ENGINEERING

Flow Failure of Liquefied Ground: Its Causative Mechanism and Prediction of Flow Displacement

IKUO TOWHATA
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University of Tokyo

Subsoil liquefaction is one of the important causes of earthquake-related damage. Since recent deposits of sand, which are composed of loosely packed sand grains saturated with water, lose stiffness and resistance against external loads, a large deformation is induced. This residual deformation destroys the function of structures and buildings. Recent studies have shown that the lateral displacement of liquefied sand can be as large as several meters.

The author has been trying to understand the mechanism of large displacement and deformation due to liquefaction and then to predict their magnitude. The final aim is to mitigate displacement-related damage. Shaking table model tests have been conducted in which a liquefiable model of sandy ground is shaken and moves substantially in a lateral direction. Observation of the deformation has detected a typical mode of soil deformation. Use of this mode facilitates development of an analytical measure by which the liquefaction-induced displacement can be predicted. Ongoing research deals with mitigation of liquefaction-induced displacement by installing underground walls in liquefiable deposits. Shaking table tests have validated this measure, and an analysis of mitigative effects of such walls has been proposed.

Frontiers in Geotechnical Earthquake Engineering

Jean-Pierre Bardet
Department of Civil Engineering
University of Southern California

Just prior to the turn of the twenty-first century, two large earthquakes struck only a few months apart in Turkey and Taiwan. The devastation was a shocking reminder that our modern infrastructures are still vulnerable when confronted with Nature's forces. As engineers and researchers, we know more about earthquakes now than we ever have in history. Yet after these two recent earthquakes, we realize that we still have much to learn about earthquake ground motion and surface faulting. We are compelled to push our engineering frontiers into new technological areas for developing safer solutions for building cities and industries in the future.

Geotechnical earthquake engineering has begun to benefit from recent technological advances for mitigating earthquake hazards. More extensive application of these technologies is envisioned for the future, through the expansion of innovative multidisciplinary geotechnical earthquake engineering research. For instance, during the 1999 Taiwan earthquakes, dense arrays of digital strong motion sensors yielded the best spatial definition to date of transient earthquake forces propagating from rupturing faults. Low-altitude Synthetic Aperture Radar (SAR) is now being considered for taking high-resolution images of permanent ground deformations, which have caused pervasive damage to utility and transportation lines during past earthquakes. SAR could also be instrumental for rapid assessment of earthquake damage and efficient deployment of rescue efforts within minutes after earthquakes. Geographic information systems will organize large volumes of information collected in the field and comprehensively disseminate this data to researchers and engineers through the Internet. Large-scale computations will simulate more realistically the propagation of earthquake waves from faults to sedimentary basins and structures. Large-scale computations will also gradually encompass a broader range of frequencies relevant to structures, will merge with

structural engineering codes, and will become integrated computational platforms for designing safer structures. With the help of Global Positioning Systems and wireless technologies, smart arrays of sensors will monitor the performance of bridges, earth dams, and other engineering systems. Information sciences will assist researchers to develop metadata repositories and integrated networks of modern large-scale experimental and computational facilities accessible on the Internet. In summary, in the face of new challenges, geotechnical earthquake engineering has embarked on a multidisciplinary journey at the frontiers of science and engineering.

Smart Structures for the New Millennium

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Graduate School of Science and Technology
Keio University

The need for a new structural system has emerged recently in Japan. The trend accelerated after the 1995 Hyogo-Ken Nanbu Earthquake in which modern engineered buildings suffered severe damage. Though the damage to those buildings was considered to be within the design scenario from a structural engineer's viewpoint, most people had believed a well-engineered building should suffer no damage to structural integrity. The recent change of the Building Standards Act, which employed performance-based design, is the key thrust for developing a new structural system, a smart structure.

Among other things, a health monitoring system to assess the integrity of a structure has been recognized as a key component of smart structures. Recent research activities reveal that current sensor and network technologies have certain limitations. For example, nondestructive damage assessment of beam-column joints in a tall steel building is very difficult without removing fire-retardant coating materials. Due to these circumstances, fiber optic sensors are attracting keen interest due to their durability, electromagnetic immunity, versatility, multiplexing capability, and possibly low production costs. An overview of smart structures and health monitoring systems will be presented.

Towards the Realization of Performance-Based Earthquake Engineering

Gregory G. Deierlein
Department of Civil & Environmental Engineering
Stanford University

While structural and earthquake engineering have in some form existed for centuries, the unprecedented technological advancements of the last couple decades are transforming how structures are designed and built. At the same time, changing socio-economic conditions are raising society's expectations for improved seismic performance of buildings, bridges, and other structures. Computing technologies have made detailed three-dimensional elastic time-history analyses routine, and sophisticated nonlinear simulations are rapidly making inroads into structural engineering practice. New materials and devices are being employed to dissipate large earthquake-induced deformations and energy with minimal damage. Networks of sensors and information management tools provide scientists and engineers with greater understanding of earthquake ground motions and their frequency of occurrence. Enabled by this environment and supported by ongoing research and development, new performance-based seismic design approaches are emerging.

This presentation will discuss the development of performance-based earthquake engineering through examples from current research and engineering and construction practice. We will begin with an overview of performance-based earthquake engineering concepts, first in a general sense and then described through a probabilistic framework that relates earthquake hazards and structural response and to desired performance targets. Recent advances in high-resolution structural simulation techniques will then be described. Finally, several innovative building projects will be featured to demonstrate applications of seismic isolators and supplemental dampers to improve performance.

Keywords

TOWHATA

Liquefaction: Earthquake shaking affects the packing of sand grains in the ground, and those grains become more densely packed. This process in the meantime increases the water pressure in the sandy deposit, causing the sand grains to be suspended in the pressurized groundwater. Consequently, the sandy ground composed of suspended grains loses its rigidity and deforms, or flows, to a substantial extent.

Permanent deformation: Since the rigidity of sandy ground is reduced substantially after liquefaction, gravity is able to generate a large permanent deformation in the ground. Typical types of deformation are subsidence of building foundations, lateral movement of gentle slopes, horizontal displacement of quay walls in ports and harbors, and floating of embedded structures. When the extent of deformation is substantial, the function of facilities is lost.

Prediction: Prediction in the field of geotechnical engineering has special features. One of them is the fact that subsoil, which is the medium to be analyzed, is a product of natural sedimentary activity. Unlike quality-controlled industrial products, soil is heterogeneous with variable material properties. The deformation and material strength of soil are affected by many factors such as pressure level, history of external loading, and direction of loading. What is important is that these complicated aspects of subsoil can be investigated only after collecting samples from the appropriate depth and running tests in the laboratory, which is a time-consuming procedure. These situations make geotechnical prediction difficult; a sophisticated technique of analysis often requires numerous types of soil data, which may not be

easily available. Thus, predictive measures have to be developed by those who understand soil behavior so that unnecessary complexity can be avoided without missing essential features.

Damage mitigation: An unacceptable magnitude of permanent subsoil deformation is the essential feature of liquefaction-induced damage. Conventionally, the onset of liquefaction has been prevented by packing sand grains more densely, injecting adhesive material into the ground, etc. Recently, lifeline industries need a less expensive way of mitigating damage so that a larger area may be saved from liquefaction-induced ground deformation. One example of such a mitigative measure is the installation of underground walls, which reduce the lateral flow of soil.

Model test: The major objective of running model tests on a shaking table is to understand the seismic behavior of earth structures, such as slopes, embankments, and harbor walls subjected to liquefaction. A model test demonstrates the overall behavior of liquefied ground and helps us understand the essential features of the phenomenon of large-deformation. Numerical analysis on the other hand, so far, cannot achieve the same goal because the deformation behavior of soil is too complicated to be fully modeled numerically.

BARDET

Geotechnical earthquake engineering: A branch of earthquake engineering that deals with geotechnical engineering problems (i.e., soil mechanics and foundations).

Synthetic Aperture Radar (SAR): A new type of imagery leading to a better definition of permanent ground deformation resulting from earthquakes.

Geographic information systems: Computer tools for archiving, displaying, and analyzing geospatial data.

Metadata: An additional layer of data that documents the acquisition and processing of data and allows users to understand how data was obtained and processed.

NEES: Network for Earthquake Engineering Simulation, a U.S. nationwide project that promotes the use of information sciences and new technologies in earthquake engineering.

MITA

Structural health monitoring: A monitoring system that detects failures of a structural system. Major targets in the civil engineering field are bridges and building structures.

Fiber optic sensor: A sensor that utilizes optical signals to detect physical response such as strain, acceleration, pressure, and others. Among them, intrinsic fiber optic sensors that utilize the optical fiber cables themselves as sensor heads are attracting keen attention for the future because of their durability and their simple structure.

Structural control: In most cases, the word "structural control" is used to describe the reduction of seismic or wind response in buildings. Devices used to achieve this task include active actuator devices and passive dampers.

Damage tolerant design: Most building structures have their ductility capability in their beam-column joints. Such structures are designed to protect human lives when subject to a severe earthquake by sacrificing such beam-column joints to absorb damaging energy that would result in permanent structural damage. Damage tolerant design is used to protect the structural system as well by introducing sacrificing devices or fuses into the structural system. By doing so, all the energy is concentrated into the sacrificing devices or fuses so that no major damage will occur in the structural system.

DEIERLEIN

Performance-based seismic design (or performance-based earthquake engineering): The term "performance-based" has been applied in many areas of engineering to distinguish between prescriptive (often empirical) design requirements versus ones that are specified in terms achieving a specified performance target (or outcome). Modern performance-based earthquake engineering is made possible by advances in seismological data and engineering technologies that enable accurate assessment of structural response to earthquake ground motions. The overall goal is to engineer constructed facilities by explicitly considering the risk to varying level earthquake hazards.

Seismic base isolation: Seismic base isolation is a technique to reduce the transmission of earthquake-induced forces and deformations into building and bridge structures. Seismic isolators can be one of several types (either sliding or deformation devices), but the basic concept of all isolators is to permit large relative deformations between the structure and its supports. Isolators work best for stiff structures since they operate in the low frequency range and have been applied to both new structures and to seismic retrofit of historic masonry structures.

Structural simulation: Structural simulation entails the application of computer-analysis techniques (finite element and other methods) to model the nonlinear response of structures. Simulations range from detailed finite element analyses of discrete components to global analyses of large structural systems.

Damage index: Damage index refers to a mathematical function that relates the earthquake-induced response of a structure to the likely damage to structural and nonstructural components. Damage indices are an integral tool in relating the results of computer simulations to expected losses from earthquakes and other loadings.

Nonstructural components: Nonstructural components are those significant architectural, mechanical, and electrical elements of a building or bridge that are not considered a formal part of the structural system. Examples of nonstructural components in buildings would include the façade (curtain wall), interior partitions, elevators, HVAC and other mechanical systems, etc. Nonstructural components are important for seismic design since failure of these components can disrupt the functionality and safety of a facility.

Design and Integration of Functional Inorganic Materials

Atomic Structure Control of Electronic Ceramic Thin Films

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Taiyo Yuden Co., Ltd.

The growth of commercial and consumer wireless markets has resulted in the realization of smaller and lighter handsets with passive chip components downsized to 0402 case-size (1.0mm × 0.5mm × 0.5mm). However, the need for a large number of passive chip components for impedance matching and filtering continues to increase. While integration has reduced the semiconductor count, similar integration has not occurred for passive components, which occupy a major fraction of the board area and contribute significantly to component and assembly cost. As a one-chip solution, the monolithic microwave integrated circuit (MMIC) has a number of limitations. Specifically, the spiral inductors and the polymer or amorphous capacitors show poor component performance (large area and large loss). Such problems became more significant as frequency increases. A technology is needed that provides high-performance passive thin film components. The low-loss can be achieved theoretically by elimination of crystal defects, such as propagation of threading dislocations, and by choosing crystal structures with a higher symmetry of harmonic oscillation of atoms. Ceramic thin films with atomic structural design and control can provide enhanced performance and achieve effective integration of passive components.

From Smart Materials to Smart Systems

NESBITT W. HAGOOD
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Massachusetts Institute of Technology

Solid state sensing and actuation devices are receiving increasing attention as critical technologies for the control of a broad range of electromechanical systems. The program at the Massachusetts Institute of Technology (MIT) in solid state actuation and applications will be presented. The program is vertically integrated from fundamental materials science on new actuation materials to inclusion of those materials in devices and the use of those devices in active control systems for vibration and noise suppression. In particular, in the area of materials, the fundamental actuation capabilities of solid state actuation materials will be compared to existing actuation technologies. The recent work in single crystal ferroelectrics actuators at Pennsylvania State University and MIT will be discussed in this context. Actuation device developments will be presented in three areas: Active Fiber Composites (AFC's), high efficiency stroke amplification systems for stack actuators (X-frame actuator), and piezoelectric rotary ultrasonic motors. Also, the use of these actuators in active control of rotorcraft vibration, aircraft interior noise, and torpedo-radiated noise will be presented with the emphasis on issues of actuation integration. Finally, research directions in solid state microhydraulic transducers for actuation and personal power generation will be introduced.

Direct Fabrication of Ceramics: A New Approach in Materials Manufacturing

DUANE B. DIMOS
Ceramics Materials Department
Sandia National Laboratories

Direct fabrication processes are defining a revolutionary new approach for materials manufacturing that is leading to a capability for producing parts quicker, cheaper, and with more functionality than previously thought possible. The key aspect of these direct fabrication techniques is the ability to deposit or build up material only where it is required to produce finished parts. The additive nature of these processes leads to tremendous flexibility in the shape and complexity of parts that can be fabricated.

Current work on direct fabrication, also called solid freeform (SFF) or additive fabrication, can be directly traced to early developments in rapid prototyping. As rapid prototyping techniques, such as stereolithography, started to become well established, the focus shifted to finding ways of producing finished parts from 3-D computer models as opposed to just plastic prototypes. Currently, numerous techniques are being developed to directly fabricate ceramics, metals, engineering plastics, composites, and electronic components. The techniques range from slurry-based processes to ink-jet writing to laser-based techniques. These methods are especially powerful for making advanced ceramics and composites, due to the inherent difficulty in manufacturing this class of materials.

This talk will provide an introduction to direct fabrication and will briefly describe several different techniques presently being developed and commercialized. Numerous examples will be provided on how to use these new manufacturing approaches to design and make materials that were either difficult or impossible to make using conventional techniques. In this respect, the direct fabrication approach opens up new design space for engineers that should lead to tremendous opportunities.

Bilateral Improvement of Mechanical and Electric Functions in Ceramic Materials

AKIRA KISHIMOTO
Institute of Industrial Sciences
University of Tokyo

Ceramic material is broadly divided into structural ceramics and functional ceramics according to the main property used. Structural ceramics use mechanical properties characteristic with high-temperature durability, and functional ceramics use a variety of electro-magnetic properties. Each field has developed almost separately, because the former is based on classical mechanics, and the latter is based on quantum mechanics. There has been almost no interaction between the two areas although many materials such as alumina, silicon carbide, and zirconia are used for both mechanical and electric purposes. Collaboration between the two fields would improve the total performance of ceramics and might create a novel function or usage. In practice it is desirable to develop structural ceramics incorporated with electric functions and functional ceramics powered by the ideas of structural ceramics. In this talk I will discuss the improvement of structural reliability through an electric screening (high-voltage screening) method and controlling the strength of a ceramic composite by using an electric field.

Keywords

FUJIMOTO

Ceramic chip components: Ceramic chip components, such as multilayer ceramic capacitors and multilayer inductors, were developed for automated high-density surface mounting on printed circuit boards, which have standardized sizes such as 0402 case size (1.0mm × 0.5mm × 0.5mm).

Multilayer Ceramic Capacitor (MLCC): MLCCs are fabricated by sintering laminated ceramic green sheets painted with metal paste as the internal electrode. The higher capacitance/volume value (down-sizing) can be obtained by increasing the number of dielectric layers and decreasing the dielectric layers' thickness.

Low-Temperature Co-firing Ceramic (LTCC): LTCC is a glass-ceramic which can be sintered under 900°C. Therefore, high-conductive metal (Ag or Cu) is co-fireable. LTCC systems are available for the most demanding high-frequency applications.

Monolithic Microwave Integrated Circuit (MMIC): MMIC is a microwave circuit in which the active and passive components are fabricated on the same semiconductor substrate. The frequency ranges from 1GHz to well over 100GHz.

Epitaxy: Epitaxy describes a technique of crystal growth by chemical reaction used to form, on the surface of a crystal, thin layers of materials with lattice structures identical to those of the crystal.

Perovskite: Perovskite structural materials are ternary compounds of formula ABO_3. The perovskite family includes many titanates used in electronic ceramics applications.

Dislocation: Dislocation is a displacement in a perfect crystal lattice, which results from a virtual shearing process. An edge dislocation appears as an extra half-plane of atoms.

HAGOOD

Piezoelectric transducers: Any of a broad range of materials (polymer or ceramic) capable of converting mechanical energy (stress and strain) into electrical energy (charge and voltage) and vice versa.

Smart structure: A structural system capable of sensing and/or controllably responding to its environment through the inclusion of sensing, actuation, and/or information processing elements.

Active vibration control: The process of controlling structural vibration (and similarly, structurally transmitted noise) using a real-time system composed of sensors, controllers, and actuators.

Microelectromechnical system (MEMS): A small scale device (sensor, actuator, pump, generator, etc.) manufactured using any of a broad set of microfabrication technologies, typically in silicon with micron-level features.

DIMOS

Direct fabrication: Any fabrication method that puts material down only where it is required and that, consequently, is used to produce near net shape parts directly.

Ceramic processing: The combination of process steps used to manufacture ceramic parts. Typically the steps used in fabricating ceramic components are: powder preparation, powder granulation, powder pressing into a die, removal of the pressed part from the die, firing to densify the part, and machining to finish the part. The direct fabrication techniques are designed to reduce processing steps and improve design flexibility.

Rapid prototyping: The family of processes used to rapidly produce part models. These models are usually plastic and are generally used during the design phase to check form and fit. The main techniques are stereolithography and selective laser sintering.

Novel structures: In the field of direct fabrication, novel structures are parts that can be produced due to the additive nature of these processes, that could not be produced, or could only be made with great difficulty using standard manufacturing processes.

KISHIMOTO

Microstructure of ceramics: Ceramics are usually fabricated by sintering starting powders. During the sintering process, the powders grow to become large grains in the order of micrometers to several tens of micrometers, and densification occurs. Then the final product consists of grains and grain boundaries. Sometimes several pores exist.

Weibull statistics: Weibull statistics are commonly used for estimating the distribution based on the weakest link theory, in which the weakest part determines the total property. When the fracture strength of ceramics is determined by the largest flaw belonging to the stressed area, then its distribution is known to obey Weibull statistics.

Vickers indentation: Indentation methods are originally used for estimating hardness. The Vickers indenter with a pyramid shape is the most popular indenter. When a Vickers indenter is pressed into a brittle material like ceramics, several kinds of cracks are formed, which can be used to estimate the toughness of ceramics.

Polarization treatment = poling: Holding in a large electric field. After polarization treatment, a ferroelectric ceramic is poled or residual polarization is left. A poled ferroelectric ceramic shows piezoelectric properties that transform mechanical energy to electric energy and transform the energy in the opposite way.

Discussion

FUJIMOTO

A number of interesting questions were raised following the talks by Fujimoto and Hagood. The first concerned the issue of reliability of actuators and actuator materials and whether poor reliability poses an impediment to acceptance of the technology. It was noted that these obstacles could be overcome through rigorous testing of components and attention to reliability at the beginning of system design. Another interesting question was raised on the importance of scale effects on the performance of both acceptor active materials. Fujimoto noted that their effects can be controlled and utilized for better performance. Hagood pointed out that most of the size scales dealt with precluded these concerns. Several questions were raised about the application of piezoelectric control technology to two areas: sports equipment and civil structures. The performance of the self-powered attraction system for tennis rackets was explained and contrasted with prior efforts in the field. Application to civil structures was discussed, noting the possibility of integrating active fiber composites and/or other active materials into building structures to alleviate higher frequency vibrations caused by passing traffic. Over all, the discussions were very interesting and relevant.

HAGOOD

• Reliability issues

Q: M/E devices such as ceramic actuators always face reliability issues. This is definitely an issue in the automobile field.

A: 30 years ago, M/F, multi-layered ceramics were only used in space and military applications. Now they can be used in commercial electronics.

• Cost issues

Q: What is the cost of a piezo-tennis racket, and can piezoelectrics be used in consumer products in the future?

A: $100k each. The relationship between the price and number of products manufactured is a sort of chicken and egg problem.

• Life time and failure mechanism

• High frequency noise from piezo and ferroelectric devices: There is no remarkable effect from the system.

• Size effect of perovskite material

A: We can avoid the size effect by judicious system design. For example, a thin film perovskite antenna does not show enough sensitivity; however, if we adopt adaptive phased array antenna, the sensitivity increases by 3Å`4 dB.

KISHIMOTO

Q: What about the impact of strength on high-voltage screening?

A: That depends on the material. Some ceramics break purely electrically and show almost no strength. Other ceramics break accompanied by melting or volatilization. In this case, mechanical properties degrade considerably.

Q: Can thermal conductivity be utilized for screening?

A: Thermal shock strength degradation was detectable. This is because microcracks form and propagate on thermal shock, and such microstructural changes reduce thermal conductivity.

Q: What do you think about the difference in rank between the applied fields? That is, the electric field is 2nd tensor and the stress field is 3rd tensor.

A: Mechanical strength and electric strength are essentially different, so high-voltage screening is not always equivalent to stress screening. For example, if a crack orients parallel to the tensile stress, it cannot originate as a fracture. But the same crack acts as a starting point for electric failure in a parallel electrode configuration.

Q: Do you think piezoelectric ceramics are too weak to be used as dispersoids?

A: Low mechanical strength is a problem for piezoelectric ceramic users. Experiments demonstrate the strength increase of 27MPa is comparable to the mechanical strength of barium titanate. In other words, the degree of strength change was as large as the mechanical strength of the dispersoid.

Q: To what degree was strength decreased by dispersing barium titanate in cubic zirconia?
A: In the case of 10mol% BT/zirconia, the mechanical strength of the composite was 250–270 Mpa, which was 80 to 90% of the matrix strength.

DIMOS

Q: In the robocasting technique, what limits the fabrication speed, and can it be increased?
A: The limitation on the writing speed is primarily determined by the rate of drying of the slurry, since the top layer needs to dry enough to have sufficient strength to support another layer on top. However, the speed is also partly determined by the speed of the computer-controlled stages.

Q: How does the strength of robocast parts compare to conventional ceramics?
A: Ceramic parts prepared by robocasting, such as aluminum oxide, zirconium oxide, or lead zirconate titanate, generally have the same strength as comparable ceramics prepared by conventional techniques. There can be some strength degradation when the parts are subjected to stress, which causes fracture between the layers, but this degradation is not severe.

Q: What is the minimum feature size for ceramic direct fabrication processes?
A: In general, the minimum feature size is about 50 microns and achieving this feature size is very challenging. Achieving feature sizes significantly smaller than 50 microns may not be realized using the processes I described. Techniques such as laser chemical vapor deposition or dip pen lithography may be required for finer features.

Q: Are these ceramic direct fabrication techniques commercially available?
A: Some of these systems are commercially available. The micropen system for direct write circuits is, and it uses standard screen printable slurries and inks. The stereolithography and the fused deposition modeling systems are commercially available, but the ceramic-loaded resins and fibers are not. However, commercial availability will improve as these techniques become more widely used.

MANUFACTURING

Sub-50 Nanometer Lithography

TAKEO WATANABE
Laboratory of Advanced Science and Technology for Industry
Himeji Institute of Technology

The density of the DRAM is quadrupling every three years. The manufacture of 16-GBit DRAMs will begin around 2006. In order to meet this schedule, a pilot exposure system has to be developed by 2004. There are several candidates for a 100-nm generation of lithography that will be used on semiconductor production lines. Of particular note is extreme ultraviolet lithography (EUVL). KrF lithography was introduced for the 180-nm generation of lithography. This technology will also be introduced for the 130-nm generation using resolution enhancement technology. Around 2004, ArF lithography will meet the specifications for the 100-nm generation. Furthermore, as for the 70-nm generation, F2 lithography has suddenly opened up and development has proceeded rapidly. However, to decrease lithography costs, multi-generation lithography is required. ArF and F2 lithography will be applied to only one generation. Only EUVL has the potential to handle feature sizes from 100-nm all the way down to 30-nm, and it can be applied to multiple generations. Work has been done in the United States, Japan, and Europe on a less-than-70-nm generation of lithography. In Japan, a national effort to achieve this was started in 1998.

Frontiers in Micromachining

GARY K. FEDDER
Department of Electrical and Computer Engineering
and The Robotics Institute
Carnegie Mellon University

The trend toward increasingly portable and embedded computers is creating new demand for perceiving and controlling our machines, structures, and environment. Investing these information systems with superior capabilities to sense and act is the eventual goal for research in Microelectromechanical Systems (MEMS). MEMS are sensor and actuator systems having critical mechanical features measured in microns and that leverage the enormous investment in mature integrated-circuit batch manufacturing. Benefits of this approach include much lower manufacturing cost, greater miniaturization, greater system integration, and in many cases higher performance than can be achieved with conventional methods used to build systems requiring sensors and actuators.

Major milestones in micromachining are too numerous to mention comprehensively, but include polysilicon surface micromachining by Howe in 1984 and the Bosch deep silicon reactive-ion-etch process in 1996. Research at Carnegie Mellon focuses on monolithic integration of MEMS with electronics to create accelerometers, rate gyroscopes for control, acoustic speaklets for hearing aids, and probe microactuators for data storage. Structures are micromachined directly from the interconnect layers existing in conventional complementary-metal-oxide-semiconductor (CMOS) processes available at low cost from foundries. An emerging design paradigm to handle the multi-physics system complexity centers around schematic design using a composable set of basic MEMS elements that are interoperable with more traditional electronic elements.

Much research associated with direct commercialization of MEMS centers on practical issues of materials and device reliability, testing, and packaging. Future research directions include exploration of microscale and nanoscale effects and

fabrication challenges for a variety of applications, with major thrusts in micro-mechanical signal processing, nanometer probe data storage, optical switching, rate gyroscopes, distributed airflow control, chemical processing, and biomolecular analysis systems.

Safety Technology Applied to the "Kibo" Japanese Experiment Module in Space

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Office of Space Utilization Systems
National Space Development Agency of Japan

The International Space Station (ISS) is a laboratory in space. It is a permanent, multipurpose manned structure under construction in Earth's orbit where a variety of experiments and observations in materials science, life science, and astronomy will be carried out. The ISS is the largest international program for space development in history. Assembly of the ISS started in November 1998, and will require approximately fifty flights to complete. The ISS is expected to operate for more than ten years. The United States, the European Space Agency, Canada, Italy, Russia, Brazil, and Japan participate in the ISS program. Japan will provide the Experiment Module "Kibo," the H-II Transfer Vehicle, and the Centrifuge Accommodation Facility. In this presentation, safety concepts applied to the Kibo and typical hazards are discussed. These safety concepts include eliminating or controlling hazards to mitigate risk and having independent organizations review hazards. Typical hazards identified in the Kibo include structural failure, depressurization, fire, contamination, and collision. A related study carried out by the National Space Development Agency of Japan is also discussed.

Keywords

WATANABE

Lithography
Semiconductor
ULSI
DRAM
CPU
New SUBARU
Extreme ultraviolet
Projection lithography
Demagnification optics
Resolution enhancement technology
Chemically amplified resist
Aspherical mirror
Reflective ask

FEDDER

Microelectromechanical systems: Microelectromechanical systems (MEMS) are sensor and actuator systems with performance derived from mechanical features measured in microns and with components numbering from a few to millions. MEMS are primarily manufactured using batch-fabrication techniques that leverage the enormous investment in mature integrated-circuit process technologies.

Process integration: Process integration is the procedure of combining disparate fabrication steps into a single process flow. This procedure is particularly challenging for MEMS, because of the desire to incorporate a variety of materials into devices for superior ability to sense and actuate.

Thermomechanical noise: Thermomechanical, or Brownian, noise is a fundamental limiting factor in the performance of inertial sensors and micropositioners. At atmospheric pressure, mechanical noise is caused from air molecules impinging on micromechanical structures.

Electrostatic actuation: Electrostatic actuation is the ability to move structures through application of an electric field across a gap. In air, extremely high electric fields (>10 MV/m) can be sustained across micron-scale gaps without breakdown.

Capacitive sensing: Capacitive sensing is a common method for detecting displacement and velocity of microstructures. Through careful attention to the capacitive transducer and circuit design, it is possible to detect sub-angstrom motion averaged over sub-second time intervals.

TAKEUCHI

Kibo: Japanese Experiment Module
ISS: International Space Station
MM/OD: Micro Meteoroid/Orbital Debris
Hazard: Existing or potential condition that can result in or contribute to a mishap.

BIOTECHNOLOGY

Beyond Human Genome Sequencing: The Challenge of Bio-Nanodevice Technology in the 21st Century

YOSHINOBU BABA
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University of Tokushima

Since over 90% of the human genome had been sequenced by June 2000, the Human Genome Project will quickly move on to the post-genome sequencing era, including single nucleotide polymorphisms (SNPs) analysis, functional genomics, and proteome analysis. In the post-human genome sequencing era, further development of technology for analyzing DNA is required for high-throughput screening of disease-causing genes in the 3.2 billion base pairs of DNA contained in the human genome; high-speed analysis of genetic polymorphism, having approximately 5-10 million sites of SNPs on an individual genome; and high-throughput clinical trials based on genotyping over 10 billion SNPs. We have been challenged to develop novel technology for ultra-fast DNA analysis using microfabricated chip-based integration of all processes required for human genome analysis. In this talk, I will provide a brief overview of the present status of the Human Genome Project as well as the development of technology for DNA analysis. The possible development of bio-nanodevice technology for post-genome sequencing projects will be discussed. I will provide a perspective on the post-genome sequencing era and DNA analytical technology, especially related to bio-nanodevices.

Modeling Intracellular Systems at Multiple Levels of Abstraction

ADAM P. ARKIN
E.O. Lawrence Berkeley National Laboratory
Howard Hughes Medical Institute

Biological regulatory networks are the circuitry that control cellular function and malfunction. The chemistry underlying the function of these networks is extraordinarily complex and difficult, if not impossible to understand knowing only a list of the parts (genes, proteins, and other chemicals) and a list of which parts react with which other parts. Just as when analyzing and diagnosing complex electronic circuits, mathematical models and computational tools for analysis and simulation are necessary if we are to understand, control, and even design our own biological and genetic reaction networks. Mathematical methods for analyzing these multiscale systems with mixed levels of abstraction are just becoming available.

In this talk we will describe our efforts at modeling bacterial genetic systems from the stochastic processes of gene expression to spatial effects in cell-cell adhesion and the mathematical and computational challenges of doing so accurately. We will demonstrate analyses of various microbial systems from phage to Bacillus subtilis and the challenges faced in understanding the "engineering principles" of control in these systems. We will also describe our efforts at creating a framework for biological data analysis and simulation to aid in these efforts.

Self-Assembly, Bio-Interface, and Nano-Probe System

MASAHIKO HARA
Local Spatio-Temporal Functions Laboratory
Institute of Physical and Chemical Research

Sensory signal processing, learning, and memory development in biological networks are central issues in current bioengineering research. While electrophysiological studies of in vivo systems are possible, it is still difficult to determine the properties of such networks at the individual molecular level. The main obstacle is the 3-D arrangement of networks that prevents the simultaneous recording of electrical and chemical events at many sites. In addition to serious problems because of tissue damage, no multiple electrode approach can provide detailed information on the morphology of the network circuits. In order to circumvent the enormous complexity of such 3-D systems, chemically patterned substrates using micro-contact printed self-assembled monolayers (SAMs) were introduced to geometrically regulate the morphology of biological macromolecules. Such controlled assemblies remained cytochemical and electrophysiological activities. Furthermore, in order to characterize these 2-D biological systems, hybridization by scanning tunneling microscopy (STM), atomic force microscopy (AFM), and scanning near-field optical microscopy (SNOM) were carried out by introducing doubly metal-coated optical fiber tips and metal-coated cantilevers. Protein molecules, for example, were sandwiched between atomically flat single crystalline substrates and metal-coated cantilevers, and the stretching force during the unfolding and refolding was monitored for a single molecule. Further capabilities of these hybridized probe microscopies are now being evaluated, and the latest progress in geometrically controlled biological assemblies and the nano-probe system will be discussed.

Drug Delivery Technologies

KATHRYN E. UHRICH
Department of Chemistry
Rutgers University

Drugs can be delivered in a controlled manner by polymers in several ways: orally, by injection, transdermally (e.g., nicotine patches), by inhalation, or through the eye (e.g., eye drops). In each method of delivery, the delivery system must meet its own set of requirements such as drug stability and release rate. For example, injectable polymer systems must water-solubilize the drug and also maintain a small size to prevent the filtration of the polymer/drug system from the blood. Yet, in all delivery systems the non-toxicity of the polymers is crucial. This talk will focus specifically on "temporary" polymers as controlled release, drug delivery systems—polymers that deliver drugs at a specific rate or to a specific location and are also degraded by the body. The non-toxicity, or biocompatibility, of the polymers must be verified as well as the polymer's degradation products. The challenges in this multidisciplinary field are to minimize the body's response (biology), maximize the drug's efficiency (pharmaceutics), synthesize the appropriate polymer (chemistry), and optimize the drug release from the polymer (engineering). By meeting these challenges, we meet the long-term goal of improving the effectiveness of drugs.

Keywords

BABA

Human genome: All of the genetic information, the entire genetic complement, all of the DNA in a person. Humanity's DNA has been called "the treasury of human inheritance." The human genome is made up of all of the DNA in our chromosomes as well as that in our mitochondria. (Each of us has, in fact, two genomes—a large chromosomal genome and a much smaller mitochondrial genome.) Our genome also includes every gene we own plus all of our junk DNA. The human genome is thus both "the treasury of human inheritance" and a vast dump (or recycling center).

DNA (deoxyribonucleic acid): One of two types of molecules that encode genetic information. The other is RNA. In humans, DNA is the genetic material; RNA is transcribed from it. In some other organisms, RNA is the genetic material and, in reverse fashion, the DNA is transcribed from it. DNA is a double-stranded molecule held together by weak hydrogen bonds between base pairs of nucleotides. The molecule forms a double helix in which two strands of DNA spiral about one other. The double helix looks something like an immensely long ladder twisted into a helix, or coil. The sides of the "ladder" are formed by a backbone of sugar and phosphate molecules, and the "rungs" consist of nucleotide bases joined weakly in the middle by the hydrogen bonds. There are four nucleotides in DNA. Each nucleotide contains a base: adenine (A), guanine (G), cytosine (C), or thymine (T). Base pairs form naturally only between A and T and between G and C, so the base sequence of each single strand of DNA can be simply deduced from that of its partner strand.

Single Nucleotide Polymorphisms (SNPs): SNPs are DNA sequence variations that occur when a single nucleotide (A, T, C, or G) in the genome sequence is altered. For example an SNP might change the DNA sequence AAGGCTAA to ATGGCTAA. Two of every three SNPs involve the replacement of cytosine (C) with thymine (T). SNPs occur every 100 to 300 bases along the 3 billion-base human genome. SNPs can occur in both coding (gene) and noncoding regions of the genome. Many SNPs have no effect on cell function, but scientists believe others could predispose people to disease or influence their response to a drug.

ARKIN

Biochemical and genetic reaction network: A set of proteins, organics, ions, and nucleic acid polymers among which there is a set of reactions that govern some biological or artificial process. Subsets of these reactions are often classified into pathways such as "Glycolysis" or "Ras-mediated signal transduction" or "cell cycle control." The word "network" implies that all reactions in the set are connected by at least one substrate or reactant.

Simulation: A process whereby the value of the observables of a system is mathematically or algorithmically described, turned into computer code, and executed on a computer. In this context, simulation will apply to the networks defined above. Simulations are used to probe the dynamics and parameter dependencies of these networks.

Dynamics: Here referring to the time-dependency of system variables. In this context, basic stochastic process theory and dynamic system theory are applied to understand control and stability in these biological reaction networks.

Database: A structured representation of data that facilitates searching and analyzing that information in a formal mathematical or computational framework. In this case, databases of biological information that interrelate information ranging from genetic sequence to time-resolved gene expression and from profiles to detailed mechanistic models of cellular processes are discussed.

UHRICH

Drug delivery: Transporting drug molecules within the body.
Controlled release: Regulating the mechanism and rate of drug molecules.
Biocompatible: Ability of a material to appropriately function in a biological environment.
Biodegradable: Ability of a material to be degraded by biological systems.

Discussion

SESSION INTRODUCTION (MIWA)

We will remember the year 2000 as the year that the human genome, the blueprint of human beings, was fully read and analyzed. This epoch-making event will have a huge impact, both on biological science and our daily lives. We would like to start our session with the genome issue, which Professor Baba will cover.

As you know, the products of DNA are proteins. Proteins play a major role in biological activities in each individual. However, networks of proteins or signal transactions through proteins are not well understood. Professor Arkin will show us his unique approach to this problem.

The next step is the cell-to-cell or cell-to-surface interaction, and the 2-D and 3-D structure of a cell complex. Dr. Hara will talk about this.

The human body is made up of 60 trillion cells. It is not easy to explain the biological activities of the human body as a complex of such a large number of cells, but there are still many approaches to studying the whole body. Professor Uhrich will tackle this issue with respect to drug delivery technology on how to convey a pharmaceutical component to the desired part of the body.

Reading the human genome is not the end of biological research. On the contrary, it is the starting point for a new era of biological and bioengineering research.

BABA

Q: Does the luminescent reagent that is used for DNA single molecule imaging change the character of DNA?

A: We use a luminescent reagent of an intercalator. It may change the physical character including the length, the stiffness, and the biological character of DNA. However, there is no other way to get a dynamic image of DNA in water solution now.

Q: What kind of SNP scoring technology looks promising for the near future?
A: After the DNA chip or the completion of SNP analysis, converting technologies such as Invator, TaqMan, and Pyrosequencing for some specific genome regions to a chip looks promising.

Q: How can you make the PCR faster by controlling the reaction temperature?
A: By making a reaction chamber of nL scale on a chip, we can easily control the reaction temperature because of its large surface area. The present chip can finish the PCR in 10-15 minutes.

ARKIN

Q: Can a simulated reaction in a homogeneous solution differ from the reaction in a cell that provides heterogeneous conditions?
A: Yes, the real reaction would be different from the simulated one. However, in 5-10 years we will be able to simulate the reaction in such heterogeneous conditions.

HARA

Q: Can you make a 3-D model of heart muscle cells? If this is possible, it would be helpful to make a heart attack model.
A: 2-D models and 3-D models are very different from each other. We have not succeeded in making 3-D models.

UHRICH

Q: Is there any difference in the metabolism of a polymer-bound drug and a free drug?
A: It would not be necessary to consider the metabolism of the polymer-bound drug.

Q: Is it possible to develop a drug delivery system with a stimulant system, for example, for releasing insulin?
A: It is an interesting and challenging issue, though I have not studied it yet.

Q: You demonstrated that the micelle is good for releasing organic molecules to the body. Can it be used for incorporating or recovering a molecule?
A: I don't think the micelle has been used for incorporating a drug, but it is often used for recovering organic molecules for environmental purposes, such as oil spills in the ocean.

Dinner Speech

A Viewpoint on Technology from My Experience

SHOICHIRO YOSHIDA
Nikon Corporation

I joined Nikon Corporation in 1956 after graduating from the Department of Technology at Tokyo University. Since then, I have worked in the optical equipment business for over 44 years as a design engineer, a manager, and in top management, and I have had many experiences. I will focus this talk on my views of the historical characteristics of technology in Japan and companies' technology strategies, and I will point out issues that Japanese companies will encounter in the 21st century.

1956 marked the end of the post-war era and the beginning of the post-war recovery. Nikon cameras were used for news coverage during the Korean War and garnered high marks from press photographers worldwide. As a result, Nikon started to grow as a camera manufacturer.

During my first six months at Nikon, I received on-the-job training at various sections in the factory. I noticed that all the machine tools and measuring instruments used in manufacturing, those regarded as standard equipment, were imports. The fact that world-renowned Nikon cameras were produced by skillfully using imported machines was characteristic of the technology level of Japanese companies.

Japan opened its door to foreign countries during the Meiji Restoration and made every effort to introduce and imitate foreign technologies with the slogan, "Catch up and overtake foreign countries." However, modern industries of foreign countries, particularly in Europe, stem from the Industrial Revolution and grew from a technology system that evolved over many centuries since the handcraft guilds era. Therefore, it was not possible for Japan to catch up with overseas countries in a couple of decades. Instead, Japan began introducing core technologies from foreign countries, resulting in a "castle-on-the-sand" technology system. Nikon's mission since its establishment more than 80 years ago has been the domestic production of optical instruments; therefore, Nikon brought engineers from Germany to train its engineers.

Japan's technology dependence on overseas countries lasted until World War II. After the war, the technology gap with the United States and Europe had widened due to the wartime hiatus. Technology from overseas was introduced in almost every industry, including the heavy chemical and petrochemical industries. In the 1970s, Japan caught up with foreign countries and nearly achieved comparable technological prowess, especially in production engineering. As far as originality is concerned, I am sorry to say that this is still not world class and is an issue to be improved in the future.

After joining Nikon, I was assigned to a project to build an astronomical telescope that would be the best in East Asia. This 36-inch reflecting telescope was installed at Kamogata in Okayama prefecture and is still being used there. As it was the first Japanese large-diameter astronomical telescope, everything, including the reflecting mirror materials, melting method, polishing, inspection, mechanical design, and so on, was a challenge to us. After studying documents primarily from the United States and Europe, it took 5 years to complete. It was ironic that at the same time we installed our 36-inch telescope on the top of the mountain, a 74-inch reflecting telescope from England was installed in a dome nearby. Their superiority to Japanese technology was obvious. Starting with this project, however, domestic production of astronomical observation instruments followed.

In parallel with designing the telescope, I was involved in domestic development of ruling engines, which are used for manufacturing optical gratings of spectroscopic measurement equipment. The ruling engine is a typical ultra-precision instrument that was developed in the United States and Europe at the beginning of the 20th century and is described in physics textbooks. Using a diamond cutter, this simple machine is capable of making more than 1,000 straight lines per millimeter on the surface of a 200 square mm glass blank. However, parallel engraving of longer than 100 mm straight lines at a pitch of 1 μm is extremely precise work and requires an accuracy of 0.01 μm. Since we used orthodox tactics, it took a long time to develop this capability. (As the proverb says: "More haste, less speed.") This type of work utilizes core technologies and requires measuring instruments for evaluating performance and machine tools for assembly and adjustment. To attain top performance required the expertise of skilled engineers rather than machine processing, and it took 3 years to achieve.

Throughout this 10-year period of work on ruling engines, I learned much about the design and production engineering of precision machines, and this has been a useful and precious experience for me. At the same time, I was satisfied because we bridged the gap between Japan and the United States or Europe in machine-building technology, even if not perfectly.

I spent my first 15 years with Nikon learning a lot about technology as an optical and precision machine designer working with astronomical telescopes and ruling engines. Even though we received high technological evaluations, from management's viewpoint this work hardly contributed to company earnings. I wondered if the know-how that we acquired from our work could be applied to

other areas and widely utilized in society. Extensive discussions with young staff members in the design group led us to set up one objective. That is, if we could combine conventional optical instruments with electronic devices, we could change conventional instruments into automated devices. We decided to call them, broadly, photoelectric sensors. They included photoelectric encoders, photoelectric microscopes, and so on, and they were developed one after another. Our ultimate objective was to develop an ultra-precision robot incorporating photoelectric sensors as eyes, a computer as the brain, and actuators as hands and feet.

In the 1970s in Japan, the semiconductor industry took off as a new strategic industry. The high integration of semiconductor devices made it difficult for human eyes to inspect the processed ICs even though microscopes were used. This trend required automated measuring instruments. Fortunately, newly developed photoelectric microscopes and laser interferometric measuring systems were needed in the semiconductor industry, and we received quite a few orders. Thus, we entered the semiconductor field.

In the late 1970s, as the semiconductor industry became more integrated, the demand grew to use our technology not only for measurement but also for VLSI manufacturing. Development to fulfill this demand took 3 years, and resulted in the step-and-repeat exposure system or stepper. This system accommodates a precise XY stage, which was brought about by photoelectric sensors and ruling engines and a newly developed computer control mechanism. This was exactly the ultra-precision robot that we had been working toward. The precision reliability and speed are far above the levels for ruling engines achieved 30 years ago. However, the production engineering and measurement technology are based on what we learned from ruling engines. This shows how important basic technology is. Fortunately, we have held the largest market share for steppers for the past 15 years—recording a cumulative shipment of over 6,500 units and a cumulative sales turnover of 2 trillion yen, assuming an average unit price of 300 million yen. The former telescope group is now contributing well to company earnings.

These have been some of my experiences during my 44 years at Nikon. Since I mentioned a fair number of technical issues, I would like to summarize them so that they may be of use to you.

1) Japan's modern industry was opened by the Meiji Restoration and grew rapidly. It was not born spontaneously but was driven and fostered by the government to catch up with foreign countries. That is why I called it a "castle-on-the-sand" technology system. Moreover, this term applies not only to technology but also to politics, the economy, the social structure, and every other system that has contradictions. Globalization and reform are being forced at this time due to this aspect.

2) In terms of technology, now that Japan has caught up with foreign countries, it is necessary to create *original* technology. In order to achieve this, it is necessary to get back to the principles of science and technology, that is, to think by

oneself and to be able to create something. That is to say, we have to reform science education. In addition, private companies need to strengthen core technologies. We at Nikon regard optics and precision engineering as our core technologies and adhere to them to enhance the value of our mission.

3) It is necessary for private companies when considering technology to have a vision. We developed core technologies in the course of building an ultra-precision robot, which led to the development of various automated instruments that met a new market demand. Each of the elemental technologies targeted for the ultra-precision robot created a synergistic effect, permitting us to accumulate much know-how. These elemental technologies include photoelectric sensors, computer control and recognition, and precision actuators.

4) To expand one's business, it is important to build relationships with growing industries. We have contributed to the growth of the semiconductor industry with our technology "seed," which we cultivated through the ultra-precision robot. This helped us grow by recognizing customers' needs and improving technologies for them. We have new business prospects in the IT, bio, and environmental industries in the 21st century. By catching new opportunities for growth, we would like to achieve the further expansion of our core technologies.

Appendixes

Contributors

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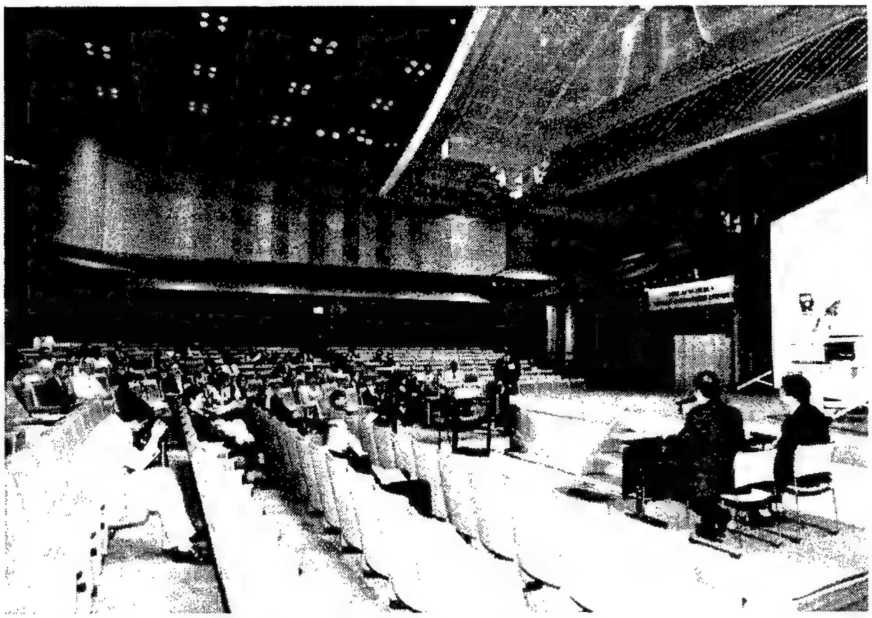

One of the speakers addresses the symposium participants.

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TAKEO WATANABE is an assistant professor at Himeji Institute of Technology. He received his B.S. degree in physics from Shimane University and M.S. and Ph.D. degrees from the Faculty of Science at Osaka City University.

SHOICHIRO YOSHIDA is president of Nikon Corporation. Mr. Yoshida graduated with a degree in precision engineering from the Department of Technology, University of Tokyo, and joined Nippon Kogaku, later renamed Nikon Corporation. He has held numerous positions at Nikon, including general manager, Design Department, Industrial Supplies and Equipment Division; director, Industrial Supplies and Equipment Division; managing director; senior managing director; and executive vice president. He assumed his current position as president in 1997.

Program

First Japan-America
Frontiers of Engineering Symposium
November 2–4, 2000
Nara, Japan

EARTHQUAKE ENGINEERING
Organizers: Jonathan Bray and Kazuo Tani

Flow Failure of Liquefied Ground:
Its Causative Mechanism and
Prediction of Flow Displacement
Ikuo Towhata, University of Tokyo

Frontiers in Geotechnical Earthquake Engineering
Jean-Pierre Bardet, University of Southern California

Smart Structures for the New Millennium
Akira Mita, Keio University

Towards the Realization of Performance-Based
Earthquake Engineering
Gregory G. Deierlein, Stanford University

* * *

DESIGN AND INTEGRATION OF FUNCTIONAL
INORGANIC MATERIALS
Organizers: Yet-Ming Chiang and Hideaki Matsubara

Atomic Structure Control of Electronic Ceramic Thin Films
Masayuki Fujimoto, Taiyo Yuden Co. Ltd.

Nara-ken New Public Hall, site of the JAFOE symposium.

From Smart Materials to Smart Systems
Nesbitt W. Hagood, Massachusetts Institute of Technology

Direct Fabrication of Ceramics:
A New Approach in Materials Manufacturing
Duane B. Dimos, Sandia National Laboratories

Bilateral Improvement of Mechanical and
Electric Functions in Ceramic Materials
Akira Kishimoto, University of Tokyo

* * *

MANUFACTURING
Organizers: James Smith and Yoshihiro Takiguchi

Sub-50 Nanometer Lithography
Takeo Watanabe, Himeji Institute of Technology

Frontiers in Micromachining
Gary K. Fedder, Carnegie Mellon University

Safety Technology Applied to "Kibo" Japanese Experiment Module in Space
Nobuo Takeuchi, National Space Development Agency of Japan

* * *

BIOTECHNOLOGY

Organizers: Tetsuo Miwa, David Tirrell, and Kenichi Yoshie

Beyond Human Genome Sequencing: The Challenge of Bio-Nanodevice Technology in the 21st Century
Yoshinobu Baba, University of Tokushima

Modeling Intracellular Systems at Multiple Levels of Abstraction
Adam P. Arkin, E.O. Lawrence Berkeley National Laboratory

Self-Assembly, Bio-Interface, and Nano-Probe System
Masahiko Hara, Institute of Physical and Chemical Research

Drug Delivery Technologies
Kathryn Uhrich, Rutgers University

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DINNER SPEECH

A Viewpoint on Technology from My Experience
Shoichiro Yoshida, Nikon Corporation

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First Japan-America
Frontiers of Engineering Symposium
November 2–4, 2000
Nara, Japan

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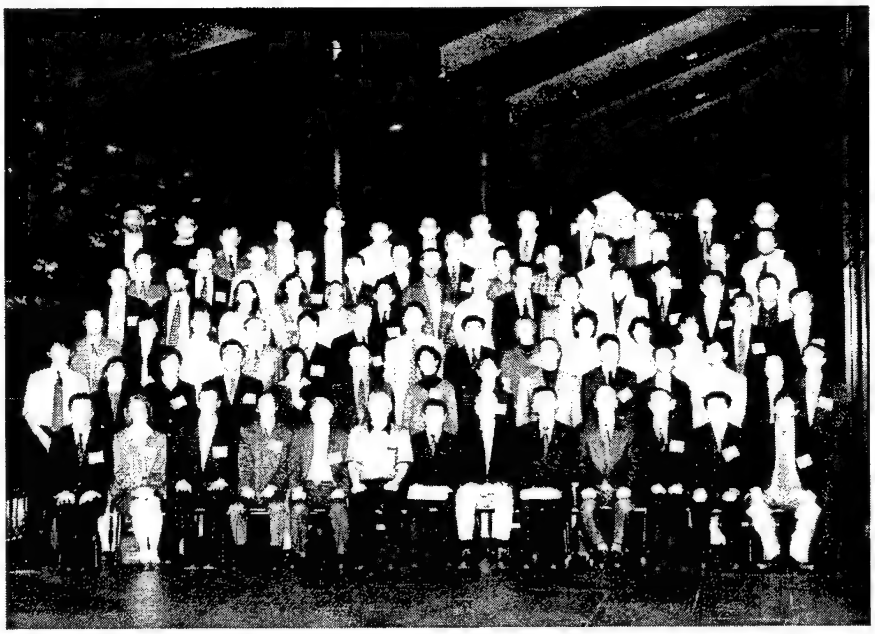

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About the U.S. National Academy of Engineering, the Engineering Academy of Japan, and the Japan Science and Technology Corporation

U.S. National Academy of Engineering (NAE)

The National Academy of Engineering is a private organization established in 1964 under the congressional charter originally granted to the National Academy of Sciences (NAS). For over 135 years, the National Academy of Sciences has provided independent,objective, scientific advice to the nation. Today, the National Academies consists of four entities: the National Academy of Sciences, the National Academy of Engineering, the Institute of Medicine (IOM), and the National Research Council (NRC). The NRC, jointly administered by the NAS and the NAE, is the operating arm of the NAS, NAE, and IOM. More than 4,800 of the nation's most distinguished leaders in science, engineering, medicine, and related fields have been selected by their peers to be members of the Academies and the Institute. These individuals and other experts serve on the hundreds of study committees active at any point in time. The NAE has about 2,000 members. In addition to supporting the work of the NRC and other elements of the National Academies, NAE conducts activities of special interest to engineers through its independent program. The Frontiers of Engineering program falls under this category of work.

Engineering Academy of Japan (EAJ)

The Engineering Academy of Japan was formed in 1987. Like the NAE, it is a private, non-governmental organization dedicated to furthering the advancement of engineering and involvement in important technology policy questions of the day.

EAJ has approximately 600 members, who are elected by their peers and hold leading positions in the Japanese technical community. In 1998, EAJ was reorganized as the Engineering Academy of Japan Inc. with the Prime Minister's permission.

The Japan Science and Technology Corporation (JST)

The Japan Science and Technology Corporation was founded on October 1, 1996 through the integration of two organizations, the Japan Information Center of Science and Technology (JICST) and the Research Development Corporation of Japan (JRDC). JST is a key organization for implementing policies of the Science and Technology Agency (STA), at present, the Ministry of Education, Culture, Sports, Science and Technology (MEXT). JICST was mainly engaged in dissemination of the information related to science and technology, while JRDC was primarily involved in the promotion of basic research, technology development and transfer, and promotion of research exchange. In addition to continuing and further developing the activities of these two organizations, JST has new objectives to provide an adequate foundation for enhancing Japan's science and technology and to promote the development of cutting-edge and innovative research in line with the Basic Law of Science and Technology enacted and promulgated on November 15, 1995, and the Science and Technology Basic Plan decided by the Cabinet in May, 1996.